A Versatile Module to Improve Understanding of Scientific Literature Through Peer Instruction

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Using primary literature in undergraduate science classes helps teach students both scientific information and process. However, students' lack of understanding of scientific techniques can hinder their understanding of the papers. We describe a "technique module" that uses peer teaching and active learning to facilitate integration of primary scientific literature into undergraduate courses.

Students find science more interesting when it is presented realistically: as a dynamic process rather than a set of stagnant facts (Tobias 1990). Therefore, undergraduate science education should teach not only scientific content, but also how scientists ask questions and make new discoveries (Handelsman et al. 2004; Handelsman, Miller, and Pfund 2007; NRC 2003; Rutherford 1990).

Including primary literature is an excellent way to introduce students to the scientific process. The reported benefits of having undergraduates read and discuss primary literature include increases in critical-thinking skills (Janick-Duckner 1997), scientific literacy (Kozertacki et al. 2006), and knowledge of scientific facts and how science is conducted (DeBurman 2002; Munix 2003).

Instructors at the University of Wisconsin-Madison designed an honors biology course that focused on reading and analyzing primary literature but found that students struggled to understand the literature because of their unfamiliarity with common
molecular biology techniques such as Western blots, Northern blots, reporter transgene assays, and immunoprecipitation (Amy Moser, personal communication). They indicated that molecular techniques are particularly difficult for undergraduates to understand because they involve complex processes at the molecular level. Ideally, students would be exposed to these techniques through a hands-on laboratory, but due to financial constraints, this was impossible. In addition, the instructors felt that understanding these molecular techniques was an essential goal of the curriculum, because these tools are the basis for research in genetics, microbiology, biochemistry, forensics, agriculture, and medicine—disciplines in which many graduates will pursue careers.

Based on the extensive literature outlining the benefits of using active learning (Ebert-May, Brewer, and Allred 1997; Handelsman et al. 2004; Springer, Stanne, and Donovan 1999; Tessier 2007; Udovic et al. 2002), peer teaching (Bargh and Schul 1980; Benware and Deci 1984; Vygotsky 1978; reviewed in Whitman 1988), and group work (Bouton and Garth 1983; Duren and Cherrington 1992; Handelsman, Miller, and Pfund 2007), we designed a “techniques module” in which student groups researched a technique and taught it to their peers. The overall goal of the module was to develop a foundation of basic knowledge regarding molecular biology techniques (e.g., use and specificity of antibodies, purpose of the blocking step, gel electrophoresis and transfer to membranes) that students could transfer to other techniques and that would help them build the skills needed to research techniques in the future. Each presenting group designed an information sheet outlining key features of an assigned technique and developed an activity to help their classmates learn about the technique. We found increases in both student comprehension and confidence following the module. This module could be easily incorporated into a wide variety of undergraduate biology courses (such as plant biology, neuroscience, and genetics) in which an understanding of molecular techniques would facilitate the use of primary literature as a learning tool.

**Design and implementation of instructional materials**

**Course context**

The biology core curriculum at the University of Wisconsin–Madison is a four-semester honors course sequence that addresses topics ranging from cell biology to evolution and genetics using lectures, discussions, and labs (Batzli 2005). The capstone course, Biological Interactions, focuses on primary literature and acts to integrate ideas from the preceding semesters. Students in Biological Interactions are generally in their third or fourth year and majoring in the biological sciences. The course includes two lecture periods and one teaching assistant–led discussion section per week, in addition to one class period during which students work in small groups to complete worksheets based on articles selected for the week (Burgess 2002). In spring 2006, the class consisted of 70 students divided into five approximately equal discussion sections. Unlike the previous three semesters in the biology core curriculum,
this course does not have a corresponding laboratory section.

In preceding years, Biological Interactions instructors integrated discussion of scientific papers as part of the curriculum. However, the instructors recognized that a lack of understanding of molecular techniques hindered their students' comprehension of the literature.

Through the Wisconsin Program for Scientific Teaching, we worked with the instructors to develop a technique module to address this concern. The module was integrated into the discussion sections in collaboration with the teaching assistants. We used the technique module for five techniques during the semester at times that corresponded to the introduction of each technique in the primary literature discussed in lecture.

**Goals of the techniques module**

We designed a module to address the main challenge that the Biological Interactions instructors had identified. Therefore, the overall goal of the unit was to help students develop the knowledge and skills needed to

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**FIGURE 2**

**Student responses to the statement “Rate your understanding of the following techniques.”**

Students reported increased understanding of techniques. The choices were: (1) I have never heard of this technique; (2) I have heard of this technique, but am unsure of what it is or how it can be used in scientific research; (3) I understand the mechanisms of how this technique works, but am unsure how to use it to ask scientific questions and interpret results; (4) I understand how this technique can be used to ask scientific questions and interpret results, but am unsure of the specific mechanisms of how it works; and (5) I understand both the mechanisms and applications of this technique.

Statement choice 5 represents a report of full understanding of the technique, and statement choice 3 or 4 represents a report of partial understanding. (A) Comparison of the percentage of students reporting full (statement 5) or partial (statement 3 or 4) understanding of each technique on the pre- and postsurveys. Data from surveys conducted during the first and last weeks of the semester. Presurvey n = 68, postsurvey n = 65. (B) Percentage of students who responded with statement choice 5 on the postsurvey, showing responses from those students who presented each technique versus those who were audience members. In each discussion section, a group of 3–4 students presented each technique to the remainder of their section (9–10 students). Data from the five discussion sections were combined. Western presenters n = 19, EMSA n = 16, IP/Co-IP n = 15, Reporter n = 15, IHC = immunohistochemistry, IP = immunoprecipitation, Co-IP = co-immunoprecipitation, Reporter = luciferase reporter assay, EMSA = electrophoretic mobility shift assay, In situ = in situ hybridization.
understand primary scientific literature in molecular biology. By the end of the module, we expected students to know how molecular techniques work and how the techniques can be used to answer research questions. Indicators that students achieved this goal include the following outcomes: Students will be able to

- explain the steps involved in common molecular techniques,
- choose the appropriate technique to address a particular question,
- apply knowledge of techniques in new contexts,
- interpret data from techniques and draw conclusions,
- use resources to gather information about new scientific techniques, and
- develop an information sheet and present an in-class exercise about one molecular technique.

In addition, we expected that students would be able to work as members of a group and that they would feel confident about their knowledge and skills.

**FIGURE 3**

Students' confidence in their ability to accomplish tasks related to the project.

Students gained confidence in their ability to perform technique-related tasks. Student responses to the statement "Rate your ability to accomplish the following tasks." Presurvey n = 68, postsurvey n = 65.

1 - Read and understand scientific literature
2 - Explain the steps involved in scientific techniques
3 - Choose the appropriate technique to address a particular question
4 - Apply knowledge of techniques in new contexts
5 - Interpret data from techniques and draw conclusions
6 - Use resources to gather information about new scientific techniques
7 - Work effectively as a member of a group

**Overview of the techniques module**

Randomly assigned groups of three to four students were responsible for teaching one of five molecular techniques to all the other students in their discussion section. Specifically, they were accountable for (1) developing an information sheet about the technique and (2) designing a corresponding activity. The information sheets provided facts, concepts, and mechanisms. The activities engaged students in critical thinking about the techniques, including self-assessment of their understanding. The assignment can be found in the Supplementary Materials (SM 1, http://scientificteaching.wisc.edu/materials/molecular/HJTechniques.htm).

For the information sheets, students were expected to include sections on how the technique is used, how the technique works, the benefits and limitations of the technique, and a list of references. We encouraged students to use illustrations or graphic representations to clarify difficult or complex concepts. To ensure accuracy, each presenting group corresponded with instructors for review before the final version was disseminated to the class.

We anticipated three benefits of having student-developed information sheets: (1) the presenting group would develop library and internet research skills that could be used to gather information about other techniques in the future, (2) the presenting group would attain a more thorough understanding of the technique by synthesizing and distilling the information for their classmates, and (3) the final product would be on a level that the class could easily understand.

We encouraged students to design activities that would actively engage the class in learning and thinking about each technique's mechanisms, concepts, and uses. We also encouraged students to create activities that targeted unique or difficult aspects of the techniques and that helped
them self-assess their understanding. Presenting groups were allowed 15 minutes of discussion time for their activity, which was to include a wrap-up period at the end to address any questions. They were also expected to walk through the audience and answer questions during the activity.

We modeled this approach for students by presenting the first technique, immunohistochemistry. Students presented four other common molecular biology techniques: Western blotting, electrophoretic mobility shift assay (EMSA or gel shift), luciferase reporter assay, and immunoprecipitation/co-immunoprecipitation (IP/Co-IP). Additional techniques not included in the module were described by the instructors through lectures and handouts.

Assessment
Assessment of presenting groups
We evaluated the group projects (information sheets and activities) using a rubric that addressed group skills, accuracy and completeness of content coverage, and effectiveness of the in-class activity. After using the module for one semester, we expanded our grading tool into two separate rubrics, one for the information sheet and one for the activity (SM 2 and SM 3, http://scientificteaching.wisc.edu/materials/molecular/HJTechniques.htm). The revised rubrics provide a finer scale for evaluating the quality of the student products. The information sheet rubric now addresses completeness, accuracy, clarity, creativity, and peer-assessed group participation. The activity rubric addresses choice of content, knowledge of the technique, activity design, and instructor-assessed group participation.

Evaluation of the techniques module and progress toward meeting the learning goals
We deployed a pair of electronic surveys at the beginning and end of the semester to assess student achievement of the learning goals. The survey is available online as supplementary material (SM 4, http://scientificteaching.wisc.edu/materials/molecular/HJTechniques.htm). To measure accomplishment of the goals set forth for the module, we used a series of multiple-choice questions. First, we asked students which technique should be used to address a scientific question. Students selected the most appropriate technique for scenarios such as visualizing the location of a specific protein in a sample, determining whether two proteins interact with each other, and determining the amount of a specific RNA molecule in a sample.

Next, we asked students to rate their understanding of various techniques by selecting among statements ranging from “I have never heard of...”

FIGURE 4
Student satisfaction with various aspects of the project.
Students enjoyed various parts of the project. Student responses to the open-ended question “What aspects of the technique module did you like best?” (A) Categories were created to summarize responses. Some responses were assigned to multiple categories. n = 65. (B) Example responses.

A

![Diagram showing student satisfaction with various aspects of the project]

B

"I liked the discussion and the presentations being presented by students, not teachers/professionals."

"I liked interactive activities."

"I think the idea of working in a small group to understand one technique is really nice."

"Information sheets were very helpful - I used them to study for the exams."

"I liked being able to understand the technique that I was assigned (EMSA) because while preparing to lead the activity, I was able to focus on how it was done."
this technique” to “I understand both the mechanisms and applications of this technique.” The list of techniques included 13 molecular techniques, including the five from this module and one fictitious technique as a control (Eastern blot).

We also asked students to rank themselves as “very confident,” “somewhat confident,” or “not confident” in their ability to perform the skills that represented the learning goals of the module. The skills that we asked them to rank were reading and understanding the scientific literature, explaining the steps involved in scientific techniques, choosing the appropriate technique to address a particular question, applying knowledge of techniques in new contexts, interpreting data from techniques and drawing conclusions, and using resources to gather information about new scientific techniques and concepts.

In addition to the survey as an assessment of student achievement of the learning goals, we were also able to monitor students’ progress through observations of their performance on the tasks of creating the information sheet and leading or participating in the class activities. These tasks provided continuous feedback for both instructors and students.

At the end of the semester, we also elicited student opinions about the effectiveness of the project as a learning tool. We asked them to rate the module and its individual components as “very useful,” “somewhat useful,” or “not useful” and asked open-ended questions about what parts they liked best and how the module contributed to their learning in the course.

Results

At the conclusion of the technique module, our assessments revealed gains in understanding of the techniques. In addition, students reported increased confidence in their understanding and abilities. Most students held positive views of the module as a learning tool.

Learning gains

Quantitative measures revealed increased comprehension of technique applications. Student understanding of which techniques were most useful for addressing various scientific questions improved dramatically during the semester (Figure 1). For each question on the postquiz, the majority of students (> 85%) chose the correct multiple-choice answer, whereas less than half were able to do so on the prequiz. Students showed gains in understanding of techniques both specifically addressed by the technique module project and those encountered as part of the course in general.

Students’ self-reported understanding of the techniques increased as
well. At the beginning of the semester, the percentage of students reporting full understanding of the techniques ranged from 1% for Co-IP and EMSA to 18% for Western blot (Figure 2A). At the end of the semester, the percentage of students reporting full understanding (choosing statement 5) was greater than 40% for each technique (Figure 2A), and the percentage reporting partial to full understanding (choosing statement 3, 4, or 5) was greater than 95% for each technique (data not shown). The exception to these trends was for the fictitious Eastern blot technique, which we included to measure students’ tendency to overestimate their abilities by falsely reporting greater understanding than they actually had. For this fabricated technique, we saw a negligible increase in reports of full understanding (from 0% on the presurvey to 3% on the postsurvey) and actually saw a decrease in reports of partial understanding (statement choice 3 or 4, from 44% on the presurvey to 19% on the postsurvey). Students reported increased understanding of techniques specifically addressed by the module and those encountered only through instruction and handouts as part of the course in general. The percentage of students reporting full understanding (choosing statement 5) increased by an average of 50 points for techniques that were included in the module and for those not included (Figure 2A, red bars). However, taking into account reports of either full or partial understanding (choosing statement 3, 4, or 5), module techniques showed greater overall gains. The percentage of students reporting partial to full understanding (choosing statement 3, 4, or 5) increased by an average of 71 points for techniques included in the module and 32 points for techniques not in the module (Figure 2A, yellow and red bars).

On the postmodule survey, students who presented a technique reported full understanding of that technique more often than members of the audience. Averaged across all techniques, 73% of presenting students reported full understanding, compared with 47% of audience members (Figure 2B).

Positive changes in confidence

Students reported increased confidence following the project in their ability to complete the science- and technique-related tasks we listed as learning goals (1–5, Figure 3). The percentage of students reporting that they were “very confident” in their ability to complete these tasks increased by an average of 33 points. Students did not report a change in confidence for their ability to use resources to gather information (59% and 60% reporting “very confident” on pre- and postsurvey, respectively) or work as a group (78% reporting “very confident” on both pre- and postsurvey).

Perceived contribution to learning

Overall, students valued participating in the module as presenters and as audience members. Ninety-five percent of students rated the project as a whole as “very useful” or “somewhat useful” (Table 1).

Students identified the information sheets as both the most useful and best aspect of the module. Not only did they value having the information sheet as a reference (98% found it somewhat or very useful, Table 1), they also indicated that creating the sheet was a useful exercise (95%,

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Percent reporting “somewhat useful” or “very useful”</th>
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<tbody>
<tr>
<td>Presenters</td>
<td></td>
</tr>
<tr>
<td>Creating information sheets</td>
<td>95%</td>
</tr>
<tr>
<td>Designing activity</td>
<td>82%</td>
</tr>
<tr>
<td>Leading activity</td>
<td>80%</td>
</tr>
<tr>
<td>Getting feedback on activity</td>
<td>71%</td>
</tr>
<tr>
<td>Getting feedback on information sheets</td>
<td>85%</td>
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<tr>
<td>Collaborating with other students</td>
<td>91%</td>
</tr>
<tr>
<td>Audience</td>
<td></td>
</tr>
<tr>
<td>Having information sheet</td>
<td>98%</td>
</tr>
<tr>
<td>Participating in activity</td>
<td>82%</td>
</tr>
<tr>
<td>Discussion about technique</td>
<td>88%</td>
</tr>
<tr>
<td>Overall</td>
<td>95%</td>
</tr>
</tbody>
</table>

Note: Student responses were to the question “How useful were the following activities in helping you understand the techniques?” Survey conducted during the last week of the semester, n = 65. Table includes ratings of tasks done as a presenter and as an audience member, and a rating of the whole project.
Table 1). Twenty-one out of 65 students listed the information sheets as the best part of the project (Figure 4). While students reported that the activities were enjoyable (14 students listed the activities as the best part of the project, Figure 4), they rated them lower than other aspects of the project in terms of usefulness. Activity-related components (designing, leading, getting feedback on, and participating in the activities) received ratings of "somewhat useful" or "very useful" from an average of 79% of students, compared with an average of 93% for information sheet components (creating, getting feedback on, and having the sheets) (Table 1).

Students also appreciated the interactive nature of the project; they found collaborating with other students and discussing the techniques useful (91% and 81%, respectively, Table 1) and several (12 students) identified it as the best feature (Figure 4).

When asked an open-ended question about what role the techniques module played in helping them learn course material, several students identified a specific learning goal that the module helped them achieve. For example, 15 students reported that the module helped them understand scientific papers, 8 with technique uses/choices, 6 with understanding technique methods/steps, and 5 with data interpretation (Figure 5). Others said it played a more general role in helping them understand the techniques in papers (18 students) or clarifying and providing general information (18 students).

Discussion

Our module was designed to aid students in understanding scientific techniques by having them research a molecular technique and teach it to their peers. Each student group developed an information sheet and an activity that engaged the class in learning the mechanics and applications of a molecular technique. Completing this project helped students gain the skills necessary to read scientific literature that relies on molecular biology techniques.

Effectiveness of the technique module

We have presented both subjective (Figures 2 and 3) and objective (Figure 1) measures demonstrating increases in comprehension, ability, and confidence after completion of the module. Our assessments revealed improvements for techniques included in the module and those encountered only in lecture, but the average increase in the percentage of students reporting partial to full understanding was greater for the techniques that were covered by the module. Gains seen for each of the techniques probably reflect the direct impact of the technique module, the application of principles learned in the module to techniques, and class exposure. In addition to our findinds that the technique module helped students accomplish the learning goals, students found the module to be a useful and enjoyable exercise.

Strengths of the module

For presenting molecular techniques, there are several benefits of the technique module over traditional lecture alone. First, during the creation of the technique information sheets and class activities, students were engaged in thinking about the techniques and working through complex concepts themselves. In self-reported assessment of their understanding of each technique, students who presented a technique reported the highest level of understanding more often than members of the audience (Figure 2B). This suggests that students did benefit from creating and teaching the materials, which is consistent with other peer-teaching models. Second, having an in-class activity encouraged interaction between students and allowed instructors to correct misconceptions and answer questions. Also, students and instructors were able to assess the level of understanding for the techniques during the activity. The combination of initial reflection during the preparation of the information sheet and in-class participation during the activity provided multiple means and opportunities for learning.

Suggestions for improvement of the module

While the presenters benefited from preparing the materials, the activities they created varied in quality and some were not the most effective for helping their classmates learn the technique. We feel that the audience would benefit from better, more directed activities. Having the instructors create activities would improve their quality, but this would deny the presenting groups the deeper understanding they gained from preparing to teach the techniques. To enhance the audience experience, we suggest incorporating peer-evaluation forms that highlight qualities of an effective activity, such as focusing on content relevant to the learning goals and a design that provides opportunities for student interaction and self-assessment of knowledge. Critiquing their classmates’ work will help students improve the planning and execution of their own activities. Additionally, a quiz or other summative assessment could follow the activity to increase audience accountability.

Conclusion

The technique module presented here is a valuable tool for improving student understanding of molecular techniques, which is central to understanding advanced concepts in biology. By encouraging students to play a major role in teaching the tools that drive scientific exploration, we hope that they can develop a deeper comprehension of the techniques involved and the central questions addressed using the techniques.
Supplementary materials
Supplements 1–4 can be accessed at the Scientific Teaching Digital Library at http://scientificteaching.wisc.edu/materials/molecular/HJTechniques.htm
SM 1. Handout for the techniques module
SM 2. Rubric for information sheets
SM 3. Rubric for activities
SM 4. Electronic survey

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